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Evaluation of Ecological Effectiveness of Protected Areas in Northwest China

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Abstract: Protected areas (PAs) have experienced explosive growth in Northwest China over the last three decades, but their effectiveness in representing regional ecological system diversity has not attracted considerable attention. Low effectiveness would exacerbate the conservation-development conflicts, particularly those that arise as a result of the Great Western Development Strategy (GWDS). Thus, an assessment of the effectiveness of the PA network has become quite important. We proposed natural vegetation communities to represent regional ecological system diversities, and proposed Global 200 Priority Ecoregions, Important Bird Areas, and ecosystem function regions to represent important conservation areas. To determine their effectiveness, we studied the extent to which ecological system diversities and important conservation areas are represented by the existing 96 PAs. Our results indicated that the total coverage of vegetation communities in PAs in Northwest China is not sufficiently comprehensive. As the PA system has expanded, the growth in the total area of the PAs has been greater than that of their vegetation community richness. While most of the important conservation areas are covered by PAs, some regions have not yet reached the 10% threshold; further, PAs are distributed unevenly and conservation gaps remain in the region. Therefore, these regions should receive more attention when planning new PAs. It is vital that more biodiversity datasets and assessment of ecosystem function regions are integrated in order to provide a basis for the government to formulate appropriate protection and development strategies.

Keywords: conservation strategies; biodiversity; ecosystem functions; protected area effectiveness; ecological system representation

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1 Introduction

At present, protected areas (PAs) cover about 13% of the global land surface (Bertzky *et al*., 2012), an increase of 400% since the 1970s (Butchart *et al*., 2010). This figure is predicted to increase to 15%–29% by 2030 (McDonald and Boucher, 2011). Although strategic expansion of the global PA network has been emphasized, the members of the Convention on Biological Diversity (CBD) concluded that the 2010 biodiversity conservation targets have not been reached globally and proposed that at least 17% of land should be conserved effectively in PAs by 2020 (UNEP, 2010). PAs are critical components of global conservation strategies, but substantial gaps remain in their coverage of biodiversity (Rodrigues *et al*., 2004a; Le Saout *et al*., 2013). Evaluating the effectiveness of PAs is an important aspect of identifying conservation status and gaps, and can enable us to take reasonable actions according to different levels of the hierarchical organization of biodiversity, including genes, species, habitats, vegetation communities, ecosystems, and their correlated processes and

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functions (Gaston and Spicer, 2004; Gaston *et al*., 2006). Ideally, a sufficient ratio of each of the global ecosystems and vegetation communities should be protected to best allocate globally flexible conservation resources (Margules and Pressey, 2000; Jenkins and Joppa, 2009). However, existing PAs do not cover biodiversity at multiple scales (Scott *et al*., 2001;Rodrigues *et al*., 2004b; Devictor *et al*., 2007; Soutullo *et al*., 2008; Jenkins and Joppa, 2009), and when they do, their effectiveness in protection is less than expected (Leverington *et al*., 2010).

China’s economy has experienced the renowned rapid growth during the past three decades(Liu *et al*., 2008),nevertheless, the western region remains under-developed (Li *et al*., 2012). In order to reduce the economic gap between the western region and the remainder of China, and boost the region′s development, the government implemented the Great Western Development Strategy (GWDS) as a long-term national strategy. This development has focused mainly on mineral resource exploitation and refining, industrial development, and infrastructure improvement (Li *et al*., 2012). However, these economic development activities have negatively affected the environmental conditions, leading to natural resource depletion, biodiversity loss, and ecological degradation (LYU *et al*., 2013). Although central and local governments have made great efforts to protect their natural areas by the rapid expansion of PA coverage over the past three decades, the unplanned expansion of PA coverage is difficult to achieve the expected protective effect. Consequently, the re-assessment of the effectiveness of PAs is required in the face of the GWDS implementation. With limited land resources, PAs should be planned carefully to maximize their functions with regard to conservation of biodiversity and other services (DeFries *et al*., 2007; Tuvi *et al*., 2011). However, the tradeoffs between industrial or infrastructural needs and conservation needs are among the most complex challenges that developing countries face (Mora and Sale, 2011). Determining which area should be developed and which should be protected is a difficult issue for governments in Northwest China. Therefore, evaluating the effectiveness of PAs is very important for governments to identify gaps and key areas that require protection. This information can help them define significant priority conservation regions and adjust the industry layout in order to harmonize ecological and environmental needs with socioeconomic development (Margules and Pressey, 2000; Langford *et al*., 2011; Salafsky, 2011).

The effectiveness of protected areas can be assessed traditionally with the ecological impact method, which focuses on whether ecological changes or habitat destruction are alleviated in PAs (Gaveau *et al*., 2009; Ahrends *et al*., 2010). Although this method provides essential information about conservation success inside the PAs, it does not mean that undamaged habitats outside of PAs do not deserve protection. The method based on specific monitoring and report data provides detailed information about ecological, socioeconomic, and cultural values (Timko and Innes, 2009). However, many research projects have not been combined with adaptive management, and therefore, they can not provide effective feedback to, and suggestions for management. In contrast, evaluations of the coverage of PAs and ecological system and species representativeness have been used widely (Rodrigues *et al*., 2004b; Gaston *et al*., 2006; Soutullo *et al*., 2008; Jenkins and Joppa, 2009), especially for management purposes (e.g., gap analysis and PA establishment).Therefore, this method is more suitable for large-scale study in the context of the GWDS.

From the perspective of conservation management, assessment of the current situation and the development process for the establishment of PAs that represent ecological system diversity is an important foundation on which governments can adjust old PAs and establish new ones. From the perspective of sustainable development, we must identify whether important conservation areas are covered properly by the existing PA system in order to confirm and revise future development plans. This can help us understand which important areas are represented well and which are under-represented. In the face of increasing pressure to coordinate human development and biodiversity conservation, such assessments are both crucial and effective, especially in undeveloped regions (Hull *et al*., 2011). Our aim was to evaluate the extent to which ecological system diversity is represented within the PA system, to what degree the ecological system diversity covered by the PA system has accumulated since the first PA was established in 1963, and how well important areas are protected by the existing system. These results can offer strategic suggestions to governments for ways to adjust economic development activities in order to promote the coordination of industrial development and conservation goals.

2 Materials and Methods

2.1 Study region

Northwest China, traditionally including Xinjiang, Gansu, Qinghai, Ningxia, and Shaanxi provinces (regions), is located in the hinterlands of the Eurasian continent. In this study, we addressed only Xinjiang, Gansu and Qinghai. These three provinces (regions), which cover approximately 2.8×10^6 km^2, basically reflect the characteristics of this region overall (Fig. 1). The region contains crucial desert, meadow, and wetland habitats for endemic, endangered, and rare species, including *Camelus bactrianus*, *Equus caballus*, *Equus kiang*, *Pantholops hodgsoni*, and many species of birds. The main features of the terrain are mountains and basins in the northwest, and plateaus in the southeast. Most areas are in the arid and semi-arid region, characterized by interactions between westerly and monsoon climates, in which the precipitation increases gradually from west to east. Traditionally, this region has been under developed, and both the gross domestic product (GDP) and per capita GDP are well below the national average. The major population and economic development are concentrated in cities and oases, in which the GWDS is likely to plan the most mineral resource exploitation and industrial distribution in the future.

2.2 Data sources

2.2.1 Ecological system diversity

We used vegetation communities to represent ecological diversity at the ecosystem scale. A vegetation map with a scale of 1∶1 000 000 was used to assess the representation of ecological system diversity in the study region (Zhang, 2008). The vegetation map was based on a three-layer classification system: vegetation-type group, vegetation type, and vegetation formation and sub-formation. A total of 10 vegetation-type groups, 40 vegetation types, and 413 vegetation formations and sub-formations were found in the study region. Cultivated vegetation was not considered in this study. Vegetation-type groups, defined by similar life forms of constructive species and community physiognomy, served as the highest classification unit, and included broadleaf forest, conifer forest, scrub, and the like. Vegetation type, defined by similar life forms of constructive species with a consistent ecological relationship of hydrothermal conditions, was a medium classification unit.

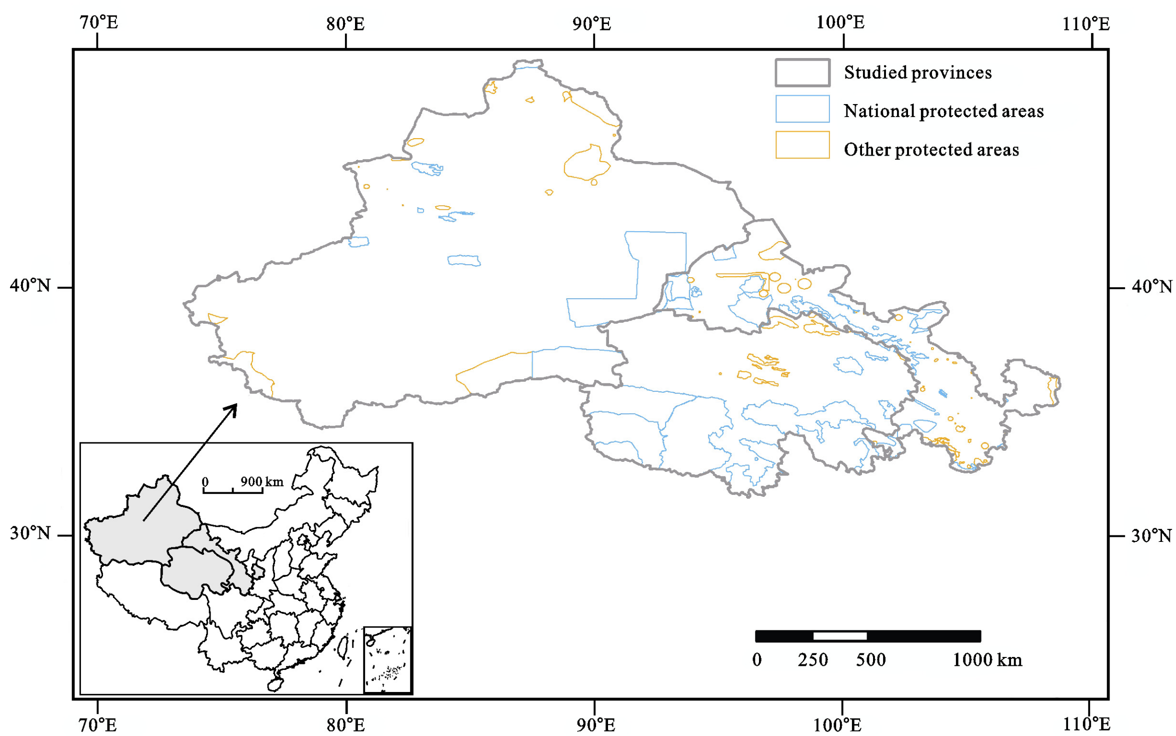

Fig. 1 Distribution of protected areas in study region

Vegetation formation and sub-formation, defined by the same constructive species or dominant species, was the lowest classification unit. We adopted vegetation formation and sub-formation as the basic research unit, which was then overlaid spatially and combined with the PAs. If higher percentages of vegetation formations and sub-formations occur in PAs, it may indicate that one type of natural vegetation has been valued and protected more intensively and extensively, and vice versa.

2.2.2 *Global 200 Priority Ecoregions* (*G200s*)

Five G200s were present in the study region. A threshold of 5% was set to select the eligible ecoregions, which indicated that >5% of an ecoregion's total area lay within the region. Only three G200 areas met the 5% minimum eligibility threshold: the Middle Asian Montane Woodlands and Steppe, Southwest China Temperate Forests, and the Tibetan Plateau Steppe (Olson and Dinerstein, 2002) (Fig. 2a).

2.2.3 *Important Bird Areas* (*IBAs*)

Fifty-nine IBAs were present in the study region (Birdlife, 2013).Because all IBAs were identified only by point location information, we buffered circular zones around all point locations based on the area information published in the IBA dataset. This polygon vector data were considered as crucial habitats for important birds (Fig. 2a).

2.2.4 *Key Ecologically Functional Zones* (*KEFZs*)

The program of National Ecologically Functional Zonation (NEFZ) was launched jointly and compiled by the Ministry of Environmental Protection and the Chinese Academy of Sciences to analyze spatial ecological features comprehensively, and define the ecosystem functions of different zones (Wu, 2007). The tasks of the NEFZ were to: 1) ascertain the structure and process of ecosystem types and their spatial distribution characteristics; 2) assess the ecosystem services of different ecosystem types and their effects on regional economic development; 3) ascertain the distribution characteristics of ecological sensitivity and highly sensitive regions, and 4) ascertain the KEFZs (Ouyang, 2007). A total of 50 KEFZs that cover 18.9% of the land surface were identified in China, 13 of which are in the study region. These 13 KEFZs require preferential selection for ecological and environmental conservation, and include six zones for water provision and retention, four for biodiversity conservation, two for windbreak and sand fixation, and one for soil conservation (Fig. 2b).

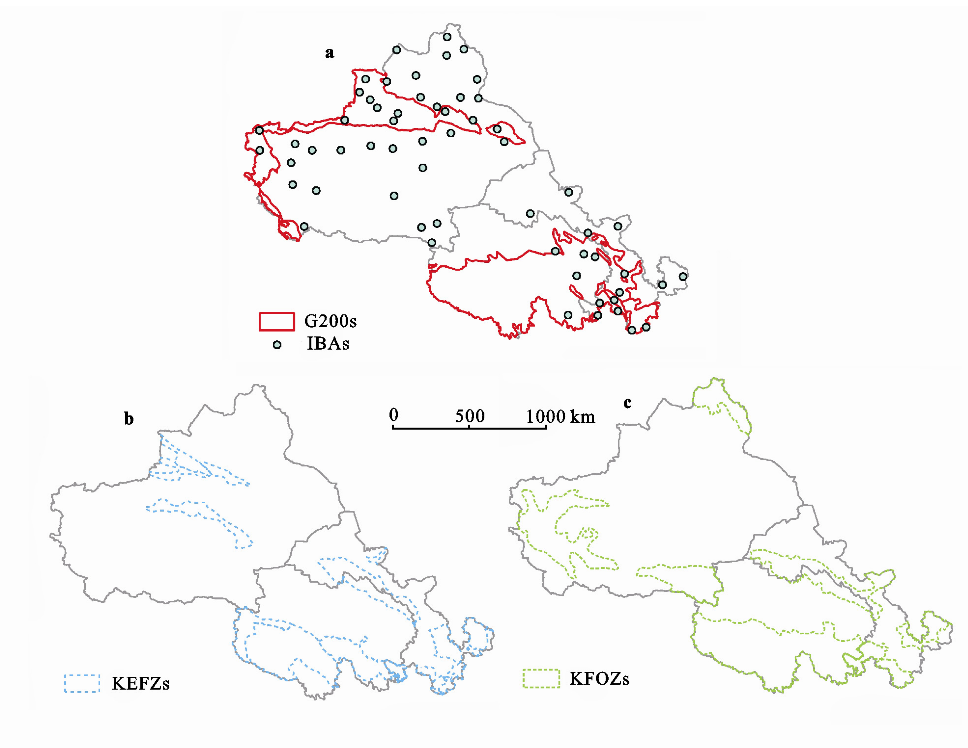

Fig. 2 Distribution of important conservation areas, including Global 200 Priority Ecoregions (G200s) (a), Important Bird Areas (IBAs) (a), and ecosystem function regions (including Key Ecologically Functional Zones (KEFZs) (b) and Key Function Oriented Zones (KFOZs) (c)) in study region

2.2.5 Key Function Oriented Zones (KFOZs)

Disorganized economic development program gave rise to conflicts between man and nature, production and living activities, and development and protection in the study region. As a result, orderly spatial development, such as rational exploitation and use of natural resources, the ecological protection of key regions, and the improvement of living environments were needed urgently. Considering the resource and environmental carrying capacity, and the future development of the population and economy, another program, the Major Function Oriented Zoning (MFOZ), was also put forward by the State Council of China during the development of the 11th five-year plan (Fang and Ding 2008). The MFOZ paid more attention to the regional economic and social attributes in order to optimize the spatial pattern of regional development and conservation, aside from considering natural attributes (Fan and Li 2009). A total of 25 KFOZs were recognized as important regions in which to restrict intense development activities in order to protect ecosystem function. Eight KFOZs exist in the study region, including fresh water provision, biodiversity conservation, soil and nutrient conservation, and windbreak and sand fixation (Fig. 2c).

2.2.6 Protected area system

Our spatial dataset of 96 PAs was collected from the recent official list of PAs representing the main components of the PA system, which was published by China′s Ministry of Environmental Protection (MEP, 2012). This dataset includes the primary information for each PA: name, date of establishment, conservation level, main conservation target, and area, among other specific details. Most large PAs contain polygon information, but some small or low-level PAs provide only point location information. Based on published area information, we buffered the centroid to create a circular zone of the appropriate size around each point location. These two sections of the PAs were merged subsequently to generate the final polygon vector data (Fig. 1). PAs are administered by four different levels of government: national, provincial, municipal, and county, respectively. PAs administered at higher levels are usually managed more strictly and systematically (Xu and Melick, 2007). Generally, national PAs (NPAs) are well managed and conserved, and have better supports, such as manpower and financial resources. Therefore, for the corresponding analysis, we divided the PAs into two datasets: all, and NPAs only.

2.3 Calculation methods

With the spatial dataset above, we assessed accumulated PA coverage for ecological system diversity according to the increase in the Pas' total areas. We used different representation thresholds to reflect the differences in conservation status of ecological system diversity (Chape *et al.*, 2005; Soutullo *et al.*, 2008; Jenkins and Joppa, 2009; Dietz *et al.*, 2015). Then, we assessed the effect of important areas protected by the existing PA system. Analyses were conducted in ArcMap 10.0 (ESRI 2010).

3 Results

3.1 Development process of protected areas

The total area of the PAs amounted to $5.269 \times 10^5 \text{km}^2$, and covered approximately 18.7% of the region′s land surface (MEP, 2012), which was three percentage points higher than the PA coverage for the country. Among these, 33 NPAs had an area of $4.101 \times 10^5 \text{km}^2$, accounting for 77.83% of the total area of all PAs. The first PA in the study region was established in 1963, but only three PAs existed before 1980, as they have experienced rapid growth only in the last three decades (Fig. 3). Half of the number was accumulated by 1992, and nearly 98% by 2005. More than half of the area was accumulated by 1995. Since 2000, the areas of both PAs and NPAs have increased dramatically, particularly those of the NPAs, whose total number and area nearly tripled from 2000 to 2012. However, the large-scale construction of PAs declined beginning in 2006.

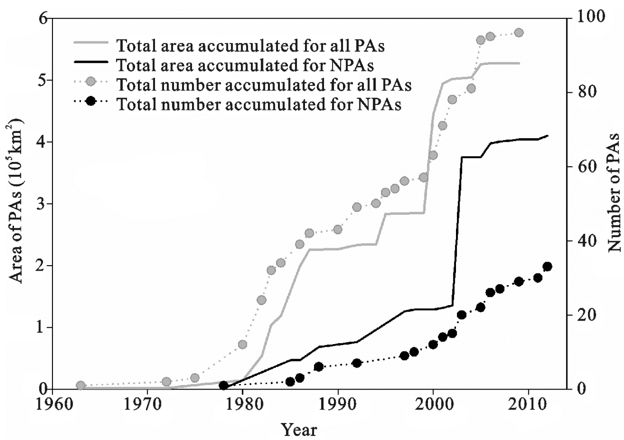

Fig. 3 Variations in numbers and areas of all protected areas (PAs) and national protected areas (NPAs) from 1963 to 2012 in study region

3.2 Vegetation communities covered by protected area system

Two hundred and eighty-five of 413 natural vegetation formations and sub-formations were protected by all the PAs, leaving 128 natural vegetation formations and sub-formations (31.0%) unrepresented in PAs, and 194 natural vegetation formations and sub-formations (47.0%) unrepresented in NPAs. The proportion of natural vegetation formations and sub-formations protected by PAs and NPAs were mapped, respectively (Fig. 4). However, when considering the number of natural vegetation formations and sub-formations that composed more than 10% and 20% of the land area in PAs, only 192 (46.5%) and 142 (34.4%) were found (Fig. 5). Thus, the PA system in the study region did not provide adequate representation of vegetation communities that exceed the 10% representation thresholds.

From the perspective of development trends in PAs and the vegetation community richness they represented, we found that new numbers of vegetation formations and sub-formations accumulated steeply from 1975 to 1987, and from 1999 to 2005 (Fig. 5a). However, the rate of accumulation was rather slow for the other years. Although more than half of the vegetation formations and sub-

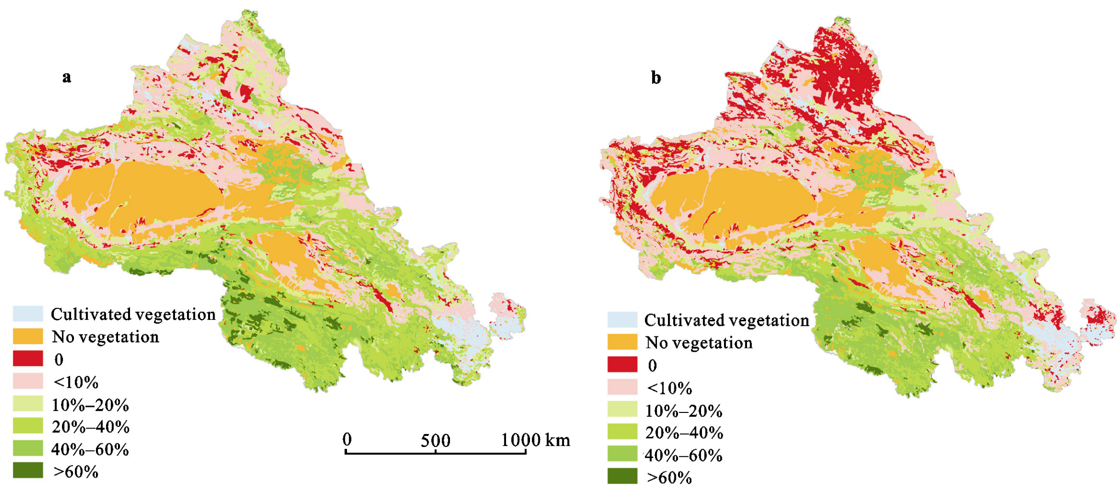

Fig. 4 Area percentages of natural vegetation formations and sub-formations protected by all protected areas (PAs) (a) and national protected areas (NPAs) (b)

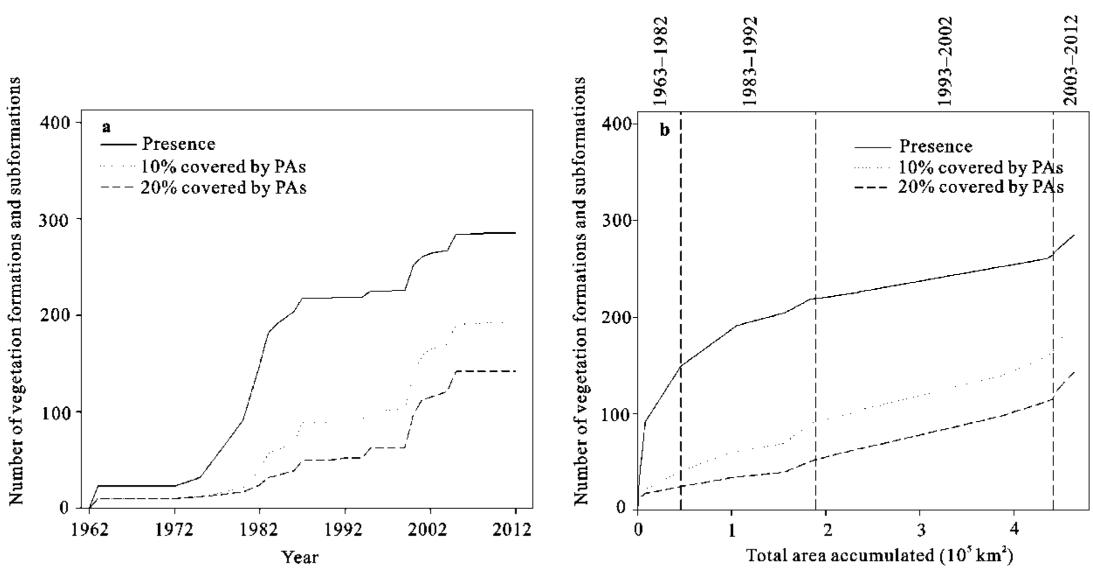

Fig. 5 Number of vegetation formations and sub-formations accumulated in protected areas (PAs) (a) and represented in PAs based on total area accumulated (b). The top of figure b represents the total number in the study region. The vertical dotted lines represent different periods

formations represented in PAs were accumulated by 1982, more than half of those at the 10% and 20% representation threshold were not accumulated until 1995 and 2000, respectively. During the first 20 years, the total area of vegetation formations and sub-formations accumulated in PAs accounted for only 10.0%, while the number of vegetation formations and sub-formations reached 52.3% (Fig. 5b). In contrast, during the fourth ten-year period, the total area of vegetation formations and sub-formations accumulated in PAs was 54.2%, while the number of vegetation formations and sub-formations in PAs was only 15.8%. Overall, the growth in total area accumulated in PAs was always larger than the growth of vegetation formation and sub-formation richness.

3.3 Important conservation areas covered by protected area system

The total area of five G200s in the study region was $8.638\times10^5 km^2$, which accounted for nearly 31% of the geographical area. Three of five G200s were eligible regions that had >5% of their total area within the region. Among those, more than 10% of the area of the region of Tibetan Plateau Steppe was contained within both PAs and NPAs, while more than 10% of the area of the region of Southwest China Temperate Forests was only contained within PAs (Fig. 6,Table 1).

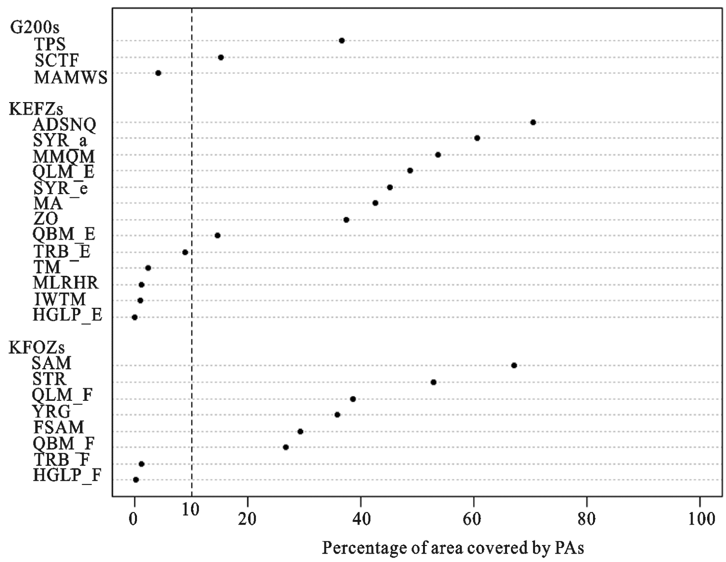

Fig. 6 Percentages of important conservation areas covered by all protected areas (PAs). G200s are Global 200 Priority Ecoregions; KEFZs are Key Ecologically Functional Zones; KFOZs are Key Function Oriented Zones; TPS is Tibetan Plateau Steppe; SCTF is Southwest China Temperate Forests; MAMWS is Middle Asian Montane Woodlands and Steppe; ADSNQ is Alpine desert steppe region of the northern Qiangtang; SYR_a is the Source region of the Yangtze River; MMQM is Minshan Mountain-Qionglai Mountains; QLM_E is Qianlian Mountains in KEFZs;SYR_e is the Source region of the Yellow River; MA is Maqu; ZO is Zoigê; QBM_E is Qinba Mountains in KEFZs; TRB_E is Tarim River Basin in KEFZs; TM is Tianshan Mountains; MLRHR is the Middle and lower reaches of the Heihe River; IWTM is Ili-western Tianshan Mountains; HGLP_E is Hill and gully region of the Loess Plateau in KEFZs; SAM is Steppe region of Altun Mountains; STR is the Source region of Three Rivers; QLM_F is Qilian Mountains in KFOZs; YRG is Yellow River water supply areas of Gannan; FSAM is Forest and steppe region of Altai Mountain; QBM_F is Qinba Mountains in KFOZs; TRB_F is Tarim River Basin in KFOZs, and HGLP_F is Hill and gully region of the Loess Plateau in KFOZs

Table 1 Percentages of three Global 200 Priority Ecoregions covered by all protected areas (PAs) and national PAs, and number of PAs in each priority ecoregion

Priority ecoregion	APSR (%)	PPA (%)	PNPA (%)	EPPA (%)	NPA	NNPA
Middle Asian Montane Woodlands and Steppe	28.46	4.23	1.38	1.20	13	4
Southwest China Temperate Forests	7.77	15.29	6.66	1.19	14	2
Tibetan Plateau Steppe	34.79	36.57	34.71	12.72	28	14

Notes: APSR, area proportion in study region; PPA, protected by PAs; PNPA, protected by national PAs; EPPA, entire priority ecoregion protected by PAs; NPA, number of PAs; NNPA, number of national PAs

Among the 59 IBAs located in study region, 30 and 22 of them were contained within existing PAs and NPAs, respectively (Table 2), leaving 29 IBAs unrepresented in PAs (Fig. 7a). 24 of the 30 IBAs contained more than 10% of their area within PAs, while 18 of the 22 IBAs contained more than 10% of their area within NPAs. Among the 29 IBAs located outside of PAs, 28 were concentrated in Xinjiang. Most of these IBAs were near different lakes, rivers, wetlands, and oases that were distributed widely across the region.

All of the 13 KEFZs were protected by PAs, eight of which contained more than 10% of their area within PAs (Fig. 6). All of the eight KFOZs were protected by PAs, six of which contained more than 10% of their area within PAs (Fig. 6). The ecosystem function regions with percentage of PA coverage below the 10% threshold were distributed primarily in the Tarim River Basin for windbreak and sand fixation, the Tianshan Mountains for biodiversity conservation and water retention, and the Loess Plateau for soil conservation (Table 3, Table 4). The majority of the ecosystem function regions were protected by NPAs—ten of thirteen KEFZs and six of eight KFOZs.

The overlaps of the KEFZs and KFOZs represented the most important regions of ecosystem functions (Fig. 7). We found that all of the nine overlaps between KEFZs and KFOZs were protected by all of the PAs, and eight were protected by NPAs. These overlaps were compared to the KEFZs and KFOZs, respectively, to determine whether crucial protection was emphasized. For instance, overlaps in the Qilian Mountains had a higher PA coverage than the two separate zones shown in blue; overlaps between the Source Region of Yellow River and the Source Region of Three Rivers had a lower PA coverage than the two separate zones shown in red. The results indicated that most of the overlaps had not embodied an increased PA coverage.

Table 2 Percentages of 30 Important Bird Areas (IBAs) covered by all protected areas (PAs) and national PAs (%)

Name	PPA	PNPA
Altay forest and steppe	26.83	0.00
Aqqik Kol and alpine grassland	100.00	100.00
Area between Qinghai Lake and A'nyêmaqên	10.22	10.22
Ayark Kol and alpine grassland	76.42	76.42
Baishuijiang Nature Reserve	42.14	39.44
Bayanbulak and Kaidu River Valley	22.22	22.22
Bogda Tianchi	20.20	0.00
Bulungkol grassland and wetland	100.00	0.00
Dunhuang Nature Reserve and western Qilian Mountains	34.12	26.46
Eastern Qilian Mountains	22.77	21.37
Ebinur Lakeand Kuytun River	86.22	86.22
Ganligahai-Zecha Nature Reserve	68.14	68.14
Gongliu spruce forest	1.13	1.13
Heshui forest region	44.62	0.00
Huanghe Shouqu Nature Reserve	97.91	97.91
Jingyu Lake	100.00	100.00
Jinta	4.97	0.00
Jonê	87.34	87.34
Kalamaili Mountains	92.04	0.00
Lianhuashan	23.13	23.13
Loess Plateau in western Gansu	2.68	2.21
Longshengou Nature Reserve	0.26	0.00
Minshan Mountain	38.84	0.00
Minqin	24.24	24.24
Mount Tuomuer Nature Reserve	65.31	65.31
Pingliang	2.55	2.55
Qinghai Lake	26.04	26.04
Sanjiangyuan Nature Reserve	33.50	28.68
Tarim Euphrates Poplar Forest Nature Reserve	67.19	67.19
Xining	6.28	6.28

Notes: PPA, protected by PAs; PNPA, protected by national PAs

4 Discussion

4.1 Gaps in existing protected area system

Protected areas are not the only tactic available to conservation planners, but they are highly cost effective in protecting biodiversity (Balmford *et al*., 2002). In light of limited human, material, and financial resources (Leverington *et al*., 2010; Laurance *et al*., 2012), PAs should be allocated and managed appropriately in order to maximize their capacity for protection. It is regretted that the expansion of the total areas of PAs in the study region did not lead to a matched increase in vegetation community richness protected inside PAs, especially during the last 20 years. Although 18.7% of the total land area is covered by PAs, 31.0% of natural vegetation formations and sub-formations is unrepresented. Unprotected natural vegetation included primarily desert plants in the Taklimakan Desert, the Qaidam Basin semi-desert, the Junggar Basin semi-desert and the Central Qinghai-Tibet Plateau, meadows in the Qaidam Basin semi-desert, steppes in the Junggar Basin semi-desert,

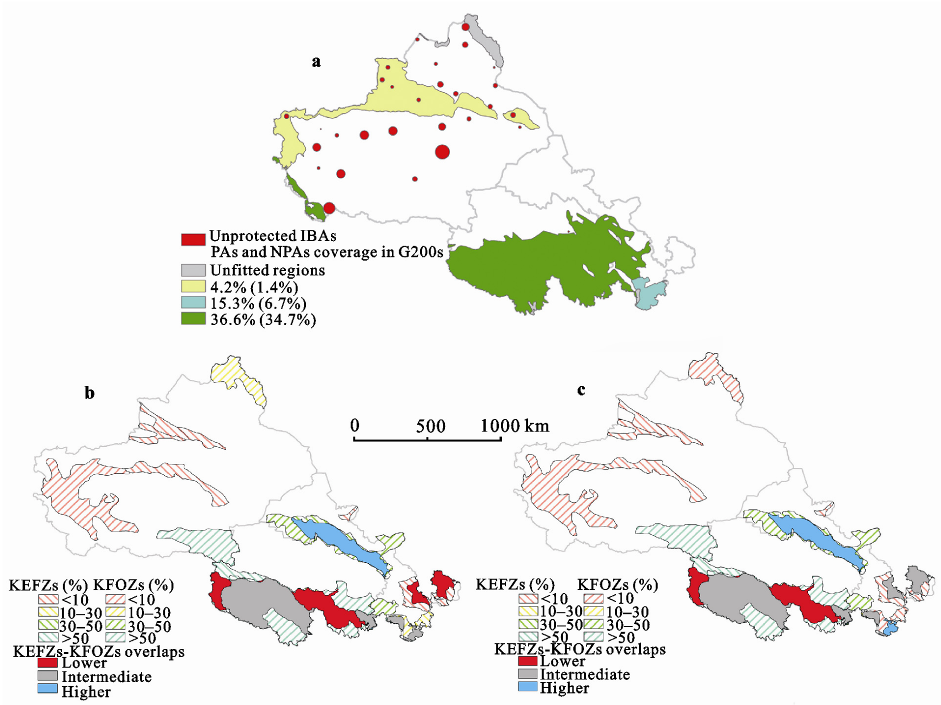

Fig. 7 Percentages of Global 200 Priority Ecoregions (G200s) protected by all protected areas (PAs) and national protected areas (NPAs) (in parentheses) coupled with unprotected IBAs (a). Percentages of Key Ecologically Functional Zones (KEFZs) and Key Function Oriented Zones (KFOZs) protected by all PAs (b) and NPAs (c). Percentages of KEFZs-KFOZs overlaps protected by all PAs (b) and NPAs (c) compared to the KEFZs and KFOZs, respectively

Table 3 Percentages of 13 Key Ecologically Functional Zones (KEFZs) covered by protected areas (PAs) and national PAs, number of PAs in each KEFZ, and attributes of major ecosystem functions in each KEFZ

KEFZ	PPA (%)	PNPA (%)	NPA	NNPA	MEF
Hill and gully region of Loess Plateau	0.09	0.00	4	0	SC
Ili-western Tianshan Mountains	0.98	0.00	2	0	BC
Middle and lower reaches of Heihe River	1.24	0.00	1	0	WSF
Tianshan Mountains	2.37	0.97	4	2	WPR
Tarim River Basin	8.82	8.82	2	2	WSF
Qinba Mountains	14.66	5.13	8	2	WPR, BC
Zoigê	37.40	37.40	2	2	WPR
Maqu	42.53	39.73	4	3	WPR
Source region of Yellow River	45.18	45.18	3	2	WPR
Qianlian Mountains	48.70	38.96	8	5	WPR
Minshan Mountain-Qionglai Mountains	53.60	14.47	6	2	BC
Source region of Yangtze River	60.64	60.64	3	3	WPR
Alpine desert steppe region of northern Qiangtang	70.54	70.54	3	3	BC

Notes: PPA, protected by PAs; PNPA, protected by national PAs; NPA, number of PAs; NNPA, number of national PAs; MEF, major ecosystem functions; WPR, water provision and retention; BC, biodiversity conservation; WSF, windbreak and sand fixation; SC, soil conservation

and marshes in the Kunlun Mountains alpine desert (Fig. 8). From this figure, ecological conservation in the areas with the greatest overlap is scarce, and should be given priority attention when planning future PAs.

Compared to other studies, the total PA coverage of vegetation communities is not sufficiently comprehensive in this region. For instance, the proportions of vegetation formations and sub-formations in PAs, measured

Table 4 Percentages of eight Key Function Oriented Zones (KFOZs) covered by all protected areas (PAs) and national PAs, number of PAs in each KFOZ, and attributes of major ecosystem functions in each KFOZ

KFOZ	PPA (%)	PNPA (%)	NPA	NNPA	MEF
Hill and gully region of Loess Plateau	0.22	0.00	2	0	SC
Tarim River Basin	1.14	0.00	2	0	WSF
Qinba Mountains	26.64	5.91	11	1	WPR, SC, BC
Forest and steppe region of Altai Mountain	29.21	4.06	5	1	WPR, BC
Yellow River water supply areas of Gannan	35.91	34.86	7	6	WPR, BC
Qilian Mountains	38.70	32.01	11	9	WPR, BC
Source region of Three Rivers	52.85	52.85	5	4	WPR, BC
Steppe region of Altun Mountains	67.18	56.28	3	2	SC, BC

Notes: PPA, protected by PAs; PNPA, protected by national PAs; NPA, number of PAs; NNPA, number of national PAs; MEF, major ecosystem functions; WPR, water provision and retention; BC, biodiversity conservation; WSF, windbreak and sand fixation; SC, soil conservation

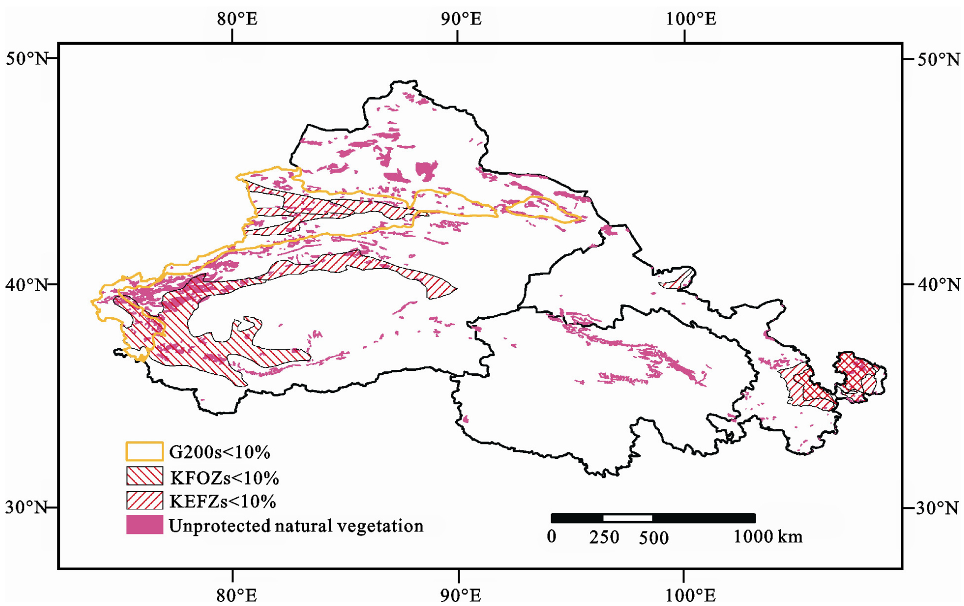

Fig. 8 Potential gaps of PAs in study region, including unprotected natural vegetation, and important conservation areas not reached 10% threshold

by both presence and the 10% representation threshold are lower in the region (69.0% and 46.7%) than they are in China overall (80.7% and 47.8%) (Wu *et al.*, 2011). Reasons for this may include: first, the distribution of PAs is too concentrated. PA coverage in Xinjiang is relatively small, such that most of the unrepresented vegetation communities are distributed primarily in that region. Second, the sizes of PAs are uneven. Nine huge PAs, all of which are larger than 10 000 km^2, constitute nearly 80% of the area of all PAs. Intensive PAs help prevent human disturbance and maintain landscape connectivity. However, they also miss important vegetation information that is fragmented in other regions. This is a distinct scale problem. Using the 10% representation threshold in PAs as an example, 46.7% of natural vegetation formations and sub-formations, 76.9% of natural vegetation types, and 90% of natural vegetation-type groups have more than 10% of their area within PAs, respectively. Therefore, we do not have the capacity to protect everything when using increasingly detailed information on vegetation. In order to make the PA system highly cost effective, both the sizes of PAs and the representation of ecological system diversity must be considered comprehensively.

Important conservation areas are not covered well by the existing PA system. Half of the IBAs, which are distributed largely in Xinjiang, are unrepresented in PAs. However, the IBA buffers are inaccurate, and some IBAs are only lakes and rivers. Therefore, not all of these regions are suitable for PAs. Important ecoregion and ecosystem function regions that have not reached the 10% representation threshold are also distributed primarily in Xinjiang. It is worth noting that the region of the Middle Asian Montane Woodlands and Steppe accounts for 28.5% of the ecoregion area in the world, but only 1.2% of its area is covered by Chinese PAs. On the contrary, the region of the Tibetan Plateau Steppe accounts for 34.8% of the ecoregion area in the world, but 12.7% of its area is covered by Chinese PAs. In order to contribute to both global and national biodiversity conservation, the region of the Middle Asian Montane Woodlands and Steppe should increase the establishment of PAs.

4.2 How to protect important ecosystem function regions

In recent years, there is an emerging body of literature suggesting the importance of protection of both biodiversity and ecosystem services (Turner *et al*., 2007; Naidoo *et al*., 2008; Larigauderie *et al*., 2012). Under the Chinese PA system, the primary purpose of PAs is to protect endangered species and natural ecosystems (Xu and Melick, 2007; Zong *et al*., 2007). Although increasing attention has focused on the protection of ecosystem functions or ecosystem services (Chan *et al*., 2006; Turner *et al*., 2007; Maes *et al*., 2012;), almost no PAs have been established with the primary purpose of protecting them. KEFZs and KFOZs are extremely important in protecting against future industrial development, especially mining activities, which have proven to be a severe threat to ecological environments in several countries because they destroy natural habitats, extend transport infrastructure, and cause pollution, among other things (Carrick and Krüger, 2007; Chauhan, 2010; Mascia and Pailler, 2011). More protection measures should be implemented for the KEFZs and KFOZs with lower PA coverage, for example, the region of the Tianshan Mountains for water provision and retention, and the region of the middle and lower reaches of the Heihe River for windbreak and sand fixation. However, even KEFZs and KFOZs with higher PA coverage still face risks from future industrial development. Because KEFZs and KFOZs have been introduced recently by the central government to strengthen ecological and environmental protection, the lack of laws and systematic protection planning has made their execution far from easy (Dai *et al*., 2013; LYU *et al*., 2013). In addition, local governments are not passionate about the protection of these areas because of the huge opportunity cost imposed by the restriction of industrial and economic development. The deal approach would be to: 1) give priority to industrial development with lower adverse ecological effects that is distributed outside PAs and key ecosystem function regions; 2) use the resources distributed outside PAs and key ecosystem function regions to replace the resources within these regions in order to decrease the ecological effects of the same resource development; 3) introduce a financial incentive on the part of the central government to harmonize the interests of all stakeholders; and 4) research and discuss ecological compensation policy (Chen *et al.,* 2010), regional effectiveness monitoring (Li *et al*., 2013), and related laws and regulations (Guo and Wang, 2011; Jackson, 2011) for the effective implementation of KEFZs and KFOZs.

4.3 Uncertainties but feasibilities involved in effectiveness assessment

Explicit spatial data for PAs in the study region remain incomplete and difficult to obtain because non-national PAs are not bound by strict management and planning, and have no legal requirement to report their explicit boundaries to the central government. As in previous studies, our original PA datasets contained point coordinates with no vector boundaries. Although errors exist between the buffers and the actual zones protected, they largely capture the PA information due to the relatively small numbers and areas of PAs. Even so, a detailed and normalized PA database must be developed as soon as possible. In this research, we used presence, and 10% and 20% representation thresholds to analyze the effectiveness of PA coverage. Percentage 10% is set as the minimum target proportion for protection, and has been endorsed as a standard by the CBD. Although land surface is not a perfect proxy for biodiversity (Tear *et al*., 2005), a consistent standard might provide a baseline framework to which different temporal and spatial scales of PA status could be compared to identify and report the remaining gaps to the appropriate governments. If the total area of PAs is increased, they will contain either new vegetation communities, or the proportion of former vegetation communities that have been protected will continue to grow. Ideally, ecological system diversity should be protected in a balanced process to reduce gaps in protection.

4.4 Importance of effective protection and suggestions for protected area management

The establishment of PAs depends on both political targets and scientifically derived goals. Generally, the government only releases superficial reports of PA status or PA coverage for political purposes; thus, the extent to which biodiversity is protected within the PA network is unclear (Rodrigues *et al*., 2004b). This study provides the current status of biodiversity and important conservation areas protected by the existing PA system in the study region. The results will be analyzed synthetically according to industrial scale and layout. The original planning will be adjusted ultimately based on an assessment of the rationality and prudence of industrial development.

The PA system is still deficient in certain areas of Northwest China, in which more lands need to be included for protection. However, the maintenance and protection of PAs requires more staff, funds, and infrastructure, which have often been insufficient due to increasing external threats (Leverington *et al*., 2010; Laurance *et al*., 2012). Uninformed expansion of more PAs is not the effective protection strategy for sustainable development. Instead, expansion of PA coverage should be based on scientific evaluation and appropriate management (Le Saout *et al*., 2013). In addition, important conservation areas should contain important habitat patches to maintain landscape connectivity. For example, important habitats for Tibetan antelope migrations in the Altun Mountain Nature Reserve must be provided (Zhao *et al*., 2014). Landscape fragmentation and habitat loss are major threats to biodiversity in Pas (Liu *et al*., 2014). Different levels of the government need to discuss collectively whether or not PAs will still be effective in the future in the face of potential threats, such as the influence of the GWDS, and they must work together to ensure that they are effective. We have provided here valuable references and a solid basis to help central and local governments select protection targets and adjust industrial planning strategically.

5 Conclusions

An effective PA network is the best tool for the conservation of ecological system diversity and functions in the face of the rapidly increasing pressure of human activities on the ecological environment. Our research indicated that 18.7% of the study region's land surface is covered by PAs, but the total PA coverage of vegetation communities is not sufficiently comprehensive in the region. With the expansion of the PA system, the growth in their total area has be enlarger than the growth of vegetation community richness in PAs. Except for the IBAs, most important conservation areas are covered by PAs, but some regions have not yet reached the 10% standard. We suggest that PA coverage of these important conservation areas should be promoted in the future. In addition, the realization of the holistic effectiveness of PAs may be achieved by combining the multi-dimensional perspectives garnered through the participation of legal, administrative, economic, and social stakeholders to harmonize biodiversity protection and development.

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